ATOMS: GET THE FACTS!

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NANOOZE

Q&A WITH HARRY KROTO

ALL ABOUT ATOMS AND BONDS

THE PERIODIC TABLE

NAMING NEW ATOMS

2011 C CHEMISTRY

International Year of CHEMISTRY 2011

NANOOZE

ALL ABOUT THE THINGS TOO SMALL TO SEE

Welcome to Nanooze!

*What is a Nanooze? (Sounds like nah-news.) Nanooze is not a thing, Nanooze is a place to hear about the latest exciting stuff in science and technology. What kind of stuff? Mostly discoveries about the part of our world that is too small to see and making tiny things using nanotechnology. Things like computer chips, the latest trends in fashion, and even important stuff like bicycles and tennis rackets. Nanooze was created for kids, so inside you'll find interesting articles about what nanotechnology is and what it might mean to your future. Nanooze is on the Web at **www.nanooze.org**, or just Google "Nanooze"—you'll find interviews with real scientists, the latest in science news, games and more!*

HOW CAN I GET NANOOZE IN MY CLASSROOM?

*Copies of Nanooze are free for classroom teachers. Please visit **www.nanooze.org** for more information or email a request for copies to **info@nanooze.org**.*

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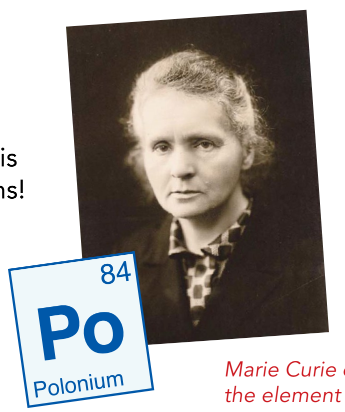
All Things are Made of Atoms and the International Year of Chemistry

All things are made of atoms. Yup. Well, almost everything. The paper that Nanooze is printed on, the ink, the staples. You, your dog. Well, not sunlight, but the little pieces of dust in sunlight that you can see swirl around the air, those dust particles are less than 100,000 nanometers in size and made mostly of atoms. For the next few issues, we're going to cover the four important concepts that are described below. First up: *All things are made of atoms.*

These issues are also devoted to the **International Year of Chemistry**, which is being celebrated around the world this year by declaration of the United Nations! It is being organized by IUPAC, the International Union of Pure and Applied Chemistry, with celebrations to be held throughout the year.



Marie Curie discovered the element polonium

One important event is the 100th anniversary of the Nobel Prize awarded to Madame Marie Curie, a very famous scientist, one of the few people to win that prestigious award twice and the only one to win it in two different fields of science: in 1903 for physics and 1911 for chemistry.

Madame Curie discovered the elements polonium and radium, and is credited with the phrase "radioactive." She used radioactive isotopes to treat neoplasms, which sometimes form cancerous tumors. A remarkable set of accomplishments!

NANO KNOW-HOW

Learning about nano stuff is fun but it can be complex, so it helps to keep these four important facts in mind:

1. All things are made of atoms.

It's true! Most stuff, like you, your dog, your toothbrush, your computer, is made entirely of atoms. Things like light, sound and electricity aren't made of atoms, but the sun, the earth and the moon are all made of atoms. That's a lot of atoms! And they're incredibly small. In fact, you could lay one million atoms across the head of a pin.

2. At the nanometer scale, atoms are in constant motion.

Even when water is frozen into ice, the water molecules are still moving. So how come we can't see them move? It's hard to imagine that each atom vibrates, but they are so tiny that it's impossible to see them move with our eyes.

3. Molecules have size and shape.

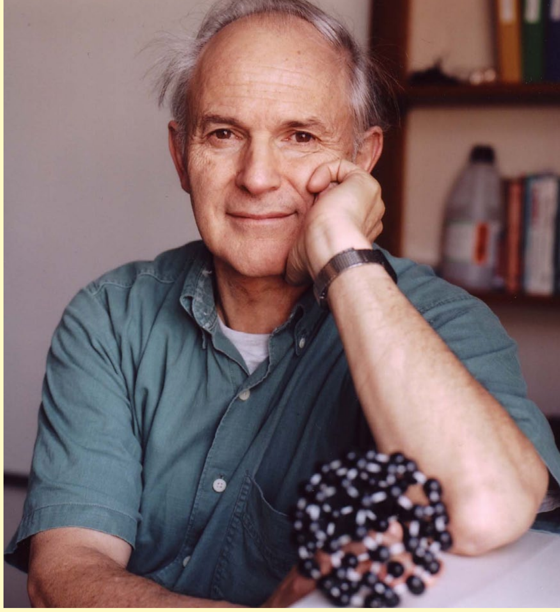
Atoms bond together to form molecules that have different sizes and shapes. For instance, water is a small molecule made up of two hydrogen atoms and one oxygen atom, so it is called H_20. All water molecules have the same shape because the bonds between the hydrogen atoms and the oxygen atom are more or less the same angle.

Single molecules can be made up of thousands and thousands of atoms. Insulin is a molecule in our bodies that helps to control the amount of sugar in our blood. It is made up of more than one thousand atoms! Scientists can map out the shapes of different molecules and can even build most types of molecules in the lab.

4. Molecules in their nanometer-scale environment have unexpected properties.

The rules at the nanometer scale are different than what we usually encounter in our human-sized environment. For instance, gravity doesn't count because other forces are more powerful at the molecular level. Static and surface tension become really important. What is cool about nanotechnology is that we can make things that don't behave like we expect. **Things are really different down there!!**

Q&A



with Harry Kroto

Chemist, professor and discoverer of the buckyball

What was your childhood like? When you were a kid what interested you about science? I spent my childhood in England. My parents came over from Germany in the late 1930s. My recollection is being a kid in the front room of my house and having an erector set to tinker with.

My family was pretty poor, but I was lucky to get into a very good school where I was interested mostly in geography and art. My father thought I should do science but I still pursued my interests in art and received some awards for my graphics. So science was not always the first thing in my life, but I was encouraged to go to college by one of my chemistry teachers.

I remember when I was a kid sending off for a kit to build a motor and then fixing things around the house that needed to be repaired. My father had a business making toy balloons—it was there that I learned some valuable problem-solving skills. Most of my studies were in science up through my Ph.D., but I did still find some time for art, playing the guitar and sports like tennis and soccer.

You moved around a lot in your career and worked in industry as well as education. Which did you like better? I worked in science at a number of different places including a research laboratory in Canada. From there I moved to Bell Labs in New Jersey. At the time, Bell Labs was one of the best places to do research anywhere. There I worked on lasers and spectroscopy.

After that, it was back to England to take a lectureship at Sussex. My salary dropped to about 10% of what I was earning at Bell Labs, but it was a chance to teach and do research. I also figured that if the science thing didn't work out I could go back to graphic design or maybe go into educational science TV. So I have been lucky to do a bunch of different things and they have all been interesting and helped shape my life.

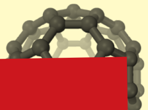
What do you find exciting about nanotechnology? Nanotechnology is a pretty new science, kind of what chemistry was like 150 years ago. In fact, nanotechnology is like 21st-century chemistry. The thing that I find most exciting is the prospect for self-assembly. We humans are assembled from the bottom up, everything is coded in our DNA. Making things that can build themselves is very cool.

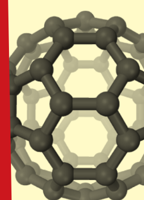
There is also some concern about how nanotechnology might be used for bad things. To tell you the truth, I am not really worried about that. I am more worried about all of the nuclear arms that a lot of countries have pointed at each other.

Before you discovered the buckyball, did you know what it might look like? The discovery of the buckyball (C60) was like a lot of great science...total serendipity. There were a lot of people that contributed to its discovery, a few of which (myself, Robert Curl and Rick Smalley) got official recognition. Chemists at the time didn't believe that this beautiful molecule could be made and made only from carbon atoms.

In 1995 you won the Nobel Prize in chemistry. I heard that they called you up on the phone. Was it a surprise? I was very excited just to be part of the scientific discovery and winning the Nobel Prize didn't make it any more exciting. On the day that they announced the Nobel Prizes, I went out to lunch with a colleague. He wanted to wait to hear the announcement, but I wanted to get something to eat.

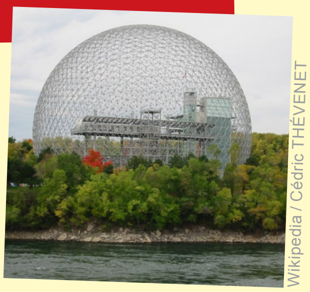
When I got back, there was a message on my answering machine. I didn't have Internet access in my office so the news reached me by a colleague screaming at the top of his voice. You get nominated for the Nobel Prize, so it wasn't a complete surprise, but for me it was because I never considered myself to be the smartest person around.





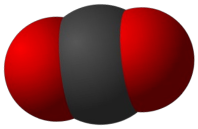
What is a buckyball?
A buckyball is a spherical molecule made of 60 carbon atoms. The full name of the molecule is *buckminsterfullerene*. It is named after Richard Buckminster Fuller, an engineer who designed spherical building structures called *geodesic domes* in the 1940s and 1950s.

Buckyball



Wikipedia / Cédric THÉVENET

A geodesic dome structure designed by Buckminster Fuller



An **atom** is the smallest particle of an element that still has the same chemical properties as that element.

Is a dog woof made of atoms?

All Things are Made of Atoms

"All things are made of atoms," so said Richard Feynman, credited by many with first imagining the field of nanotechnology. Seems simple enough: All things are made of atoms. *Everything*. Well, *almost* everything.

Sunlight isn't made up of atoms, but the streams of light we might see as the sun peeks through the window in the morning are made up of atoms, tiny dust particles that we can see only because light bounces off of them. The "Woof!" from your dog isn't made up atoms, but we hear it because of the molecules in the air between you and your dog.

The big challenge is remembering that all things are made of atoms and also remembering what an atom is.

WHAT ARE ATOMS?

So what is an atom? Well, more precisely, what are *atoms*? Atoms are the smallest pieces of matter that still retain their unique properties. When you think about the smallest thing, you probably think about atoms, neutrons, protons and electrons. All atoms contain neutrons, protons and electrons—except hydrogen, which has only one proton and one electron.

SMALLER PARTICLES

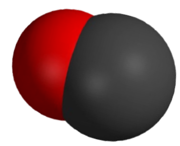
There is even smaller stuff, like quarks, muons, neutrinos and bosons. Recently in Europe, some scientists think they may have found evidence of even smaller stuff—a new particle called "Higgs," believed to give all of the fundamental particles their mass. But the scientists are uncertain if the evidence confirms the existence of these particles or if it was merely a blip on some instruments.

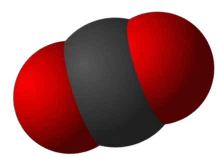
ELEMENTS

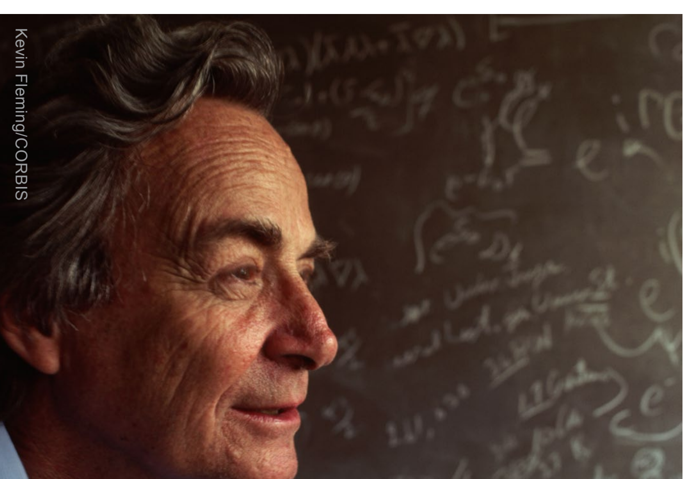
There are 118 known elements, making 118 different kinds of atoms. Sometimes atoms are found alone, other times they form pairs. Oxygen is an atom that most of the time is found as pairs. Atoms bond together to form molecules, but not all atoms bond, and not all atoms bond to other atoms. There are rules that dictate why some atoms can bond to each other and some can't.

For example, hydrogen and oxygen join together to form water—two hydrogens and one oxygen—H_20. Carbon can also join to oxygen and sometimes you get carbon dioxide (CO_2) and other times you get carbon monoxide (CO).

What determines whether you get carbon monoxide (which is dangerous to inhale) or carbon dioxide (which can make you burp) depends upon the conditions and other things when they are reacting with each other.

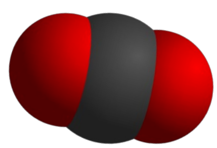




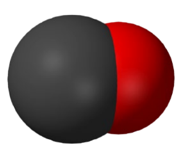


Kevin Fleming/CORBIS

Richard Feynman (1918-1988) - The American physicist who pioneered the science of nanotechnology.

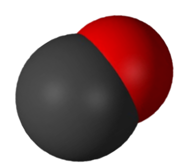


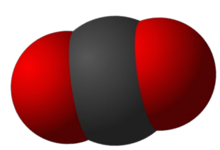
Carbon dioxide CO_2

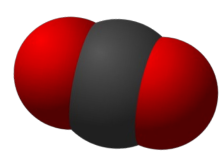


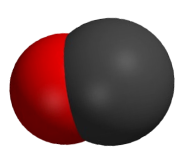
Carbon monoxide CO

Atoms and molecules are small, but **quarks**, **muons** and **neutrinos** are even smaller!

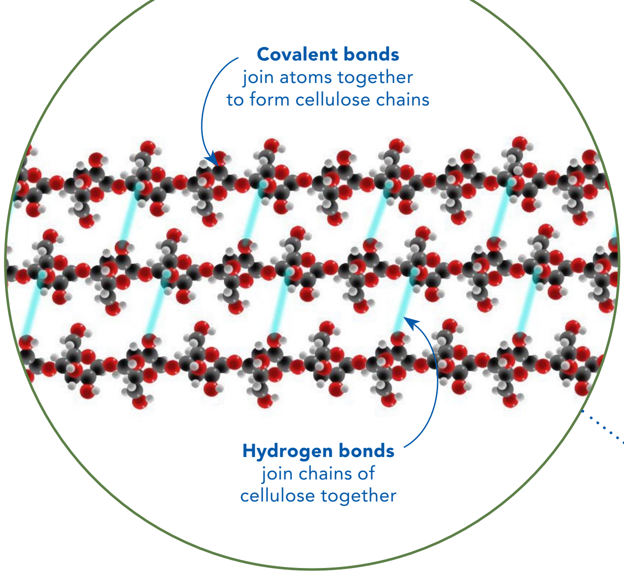






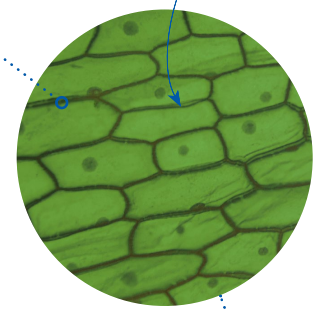


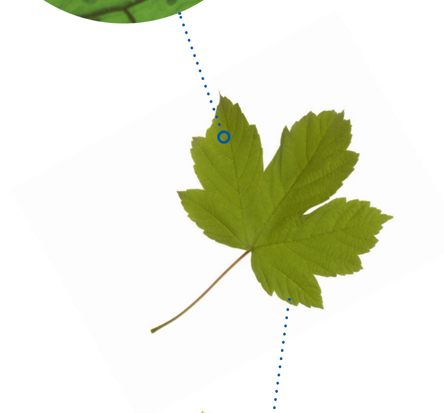
Carbon monoxide and **carbon dioxide** molecules are both made up of carbon and oxygen atoms.



Cellulose, the most common organic compound on Earth, is held together with **covalent** and **hydrogen** bonds.

The cell walls in plant cells are made up of cellulose.





Bonds Hold Atoms Together

TYPES OF BONDS

The bonds that hold atoms together to form molecules are called *covalent bonds*. They are pretty tough and not easily made or broken apart. It takes energy to make the bonds and energy is released when the bonds are broken.

Trees take light and use it to make bonds between carbon atoms and molecules of cellulose. If we burn wood, those bonds are broken and we get heat and some light. But there is more to bonds between atoms than just energy—they are also what gives a molecule its shape.

Cellulose looks like long strings if you look at it with an electron microscope. These long strings of cellulose form bundles because of another kind of bonding called *hydrogen bonding*. The shape of cellulose molecules makes it easy for hydrogen bonds to form between strings. While not as strong as covalent bonds, hydrogen bonds are still pretty strong, so it is the shape of cellulose that makes wood a strong material.

NANOTECHNOLOGY AND MOLECULES

Nanotechnology can be used to make molecules. Atoms floating around in air or in liquid can sometimes bond to form molecules, but it isn't that easy because of the rules about what can bond and what can't.

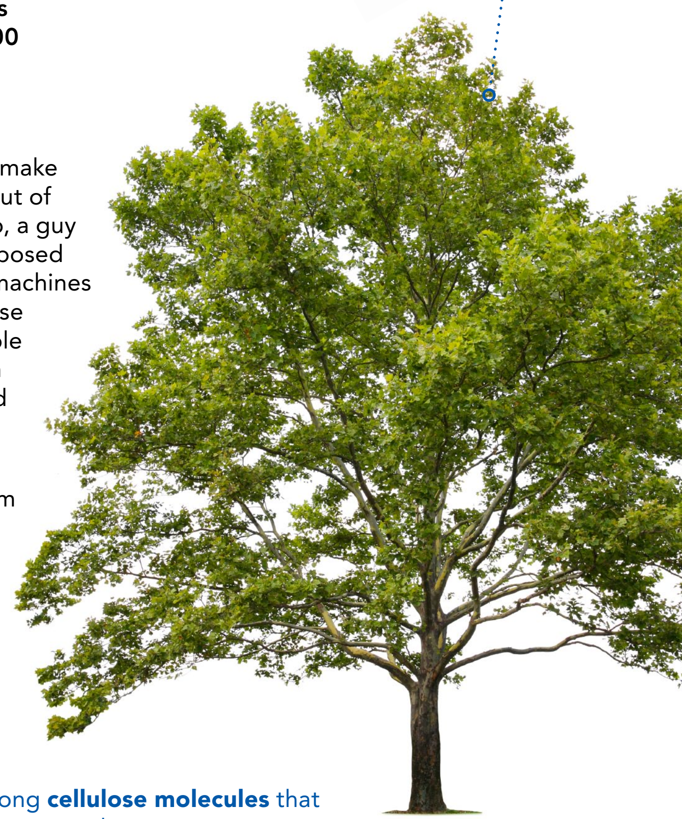
Imagine taking Lego blocks and instead of fitting them together with your hands you stood across the room from your friend and threw them at each other to try to connect them. Every once in awhile they might stick together, but it could take a million attempts to get it to work once. If you have billions and billions of molecules, well, maybe it would work.

So how many atoms are there, let's say, in a bunch of air? Lots and lots, around 2.69×10^{19} molecules in every cubic centimeter. **That's 2,690,000,000,000,000,000,000 molecules.**

THE FUTURE OF NANOTECHNOLOGY

But will we someday be able to make molecules like we build things out of Legos? Back about 30 years ago, a guy by the name of Eric Drexler proposed something like that, molecular machines that could make molecules. These machines are imagined to be able to take elements and stick them together to make molecules and bigger things the same way we make a car or a toaster.

We are still a long way away from that kind of stuff and there is a lot of controversy—if it is even possible—only time will tell!



The long **cellulose molecules** that make up wood give trees strong trunks and branches.

The Periodic Table

Organizing elements

Chemists swear by it, but for the rest of us the periodic table is like a bunch of stuff organized more like your closet at home, with things stuffed into places just because they fit. In fact, there is a method: the rows (across) are called "**periods**," the columns (up-down) are called "**groups**."

Right now there are 118 different **elements**, most of them are natural and a few are man-made. The first element on the periodic table is hydrogen (H), which has an atomic weight of 1, and the last element is something called ununoctium, which has an atomic weight of 118.

Atomic weight is the mass of the element, the weight is a total of the protons, neutrons and electrons. It is listed as an average since there is a bit of variation due to things called isotopes. **Isotopes** have a different number of neutrons, so there is carbon-12 but also carbon-13 and carbon-14. Carbon-14 is an isotope but pretty stable—the amount of carbon-14 in a sample can be used to figure out how old a biological sample is.

Groups are considered the most important way in which we classify elements—group 4A includes things like carbon, silicon, germanium and lead, all of which form stable compounds. They all have five electrons in their outermost shell, allowing them to form a lot of different compounds because the electrons can form bonds with different kinds of atoms.

Oxygen is the most abundant element on Earth.

Only the first 94 elements are believed to occur naturally on Earth. The rest have been created synthetically.

Key

11 Na Sodium 22.99 — Atomic number; Element symbol; Element name; Average atomic weight (mass)

- Other nonmetals
- Alkali metals
- Alkaline earth metals
- Transition metals
- Post-transition metals
- Metalloids
- Halogens
- Noble gases
- Lanthanides
- Actinides
- Unknown chemical properties

GROUPS / **PERIODS**

Period	1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B	10 8B	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1	1 H Hydrogen 1.01																	2 He Helium 4.00
2	3 Li Lithium 6.94	4 Be Beryllium 9.01											5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 16.00	9 F Fluorine 19.00	10 Ne Neon 20.18
3	11 Na Sodium 22.99	12 Mg Magnesium 24.31											13 Al Aluminum 26.98	14 Si Silicon 28.09	15 P Phosphorus 30.97	16 S Sulfur 32.07	17 Cl Chlorine 35.45	18 Ar Argon 39.95
4	19 K Potassium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.87	23 V Vanadium 50.94	24 Cr Chromium 52.00	25 Mn Manganese 54.94	26 Fe Iron 55.85	27 Co Cobalt 58.93	28 Ni Nickel 58.69	29 Cu Copper 63.55	30 Zn Zinc 65.39	31 Ga Gallium 69.72	32 Ge Germanium 72.61	33 As Arsenic 74.92	34 Se Selenium 78.96	35 Br Bromine 79.90	36 Kr Krypton 83.80
5	37 Rb Rubidium 85.47	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niobium 92.91	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 127.60	53 I Iodine 126.90	54 Xe Xenon 131.29
6	55 Cs Cesium 132.91	56 Ba Barium 137.33	57 La Lanthanum 138.91	72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.84	75 Re Rhenium 186.21	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.97	80 Hg Mercury 200.59	81 Tl Thallium 204.38	82 Pb Lead 207.2	83 Bi Bismuth 208.98	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
7	87 Fr Francium (223)	88 Ra Radium (226)	89 Ac Actinium (227)	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (266)	107 Bh Bohrium (264)	108 Hs Hassium (269)	109 Mt Meitnerium (268)	110 Ds Darmstadtium (281)	111 Rg Roentgenium (280)	112 Cn Copernicium (285)	113 Uut Ununtrium (284)	114 Uuq Ununquadium (289)	115 Uup Ununpentium (288)	116 Uuh Ununhexium (293)	117 Uus Ununseptium (294)	118 Uuo Ununoctium (294)

58 Ce Cerium 140.12	59 Pr Praseodymium 140.91	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.96	64 Gd Gadolinium 157.25	65 Tb Terbium 158.93	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.97
90 Th Thorium 232.04	91 Pa Protactinium 231.04	92 U Uranium 238.03	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

Hydrogen and helium are the most abundant elements in the universe.

New Atoms

How does one get the chance to name a new atom?

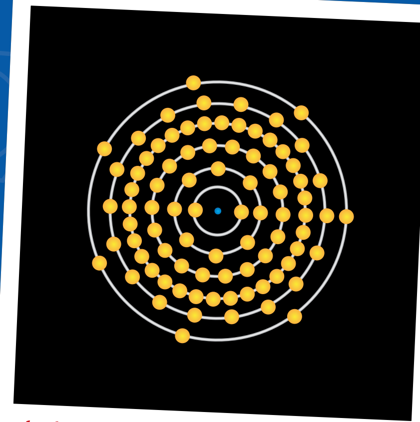
The periodic table is a list of all of the atoms that we know of. But are those all the atoms on Earth or in the universe? Back in 1982, **meitnerium** was not on the periodic table. So who discovered it and how?

New elements are still being discovered and most of them are being made in the lab. The new elements are bigger—the biggest one has 114 protons and a molecular weight of around 285, about 25 times bigger than carbon. It is called **ununquadium** and it doesn't last long, decaying almost immediately with half of it gone in about 3 seconds.

Some "new" elements have applications while others don't. For example, **californium**, which was first made in 1950, is used in moisture gauges to determine water- and oil-bearing layers in oil wells. Other elements don't stay around long enough to be very useful at all. You spend a few years trying to make them and—poof!—they decay in a few seconds.

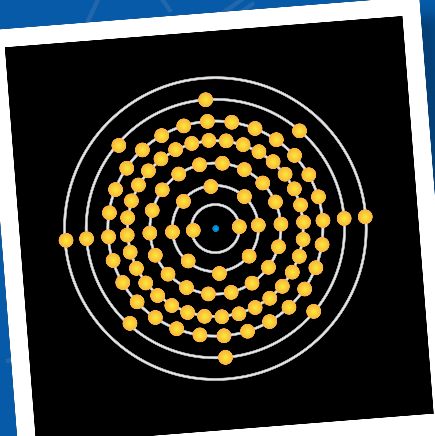
When a new element is discovered it's a pretty cool thing and whoever discovers it gets to name it. For example, **berkelium** was discovered at the University of California, Berkeley. So if anyone is interested in naming the next new element nanoozium, please let us know!

Most new elements result from smashing together different existing elements in an instrument that accelerates particles. Very recently at a lab located about 75 miles north of Moscow, Russia, a team of American and Russian scientists may have made a new element by smashing together calcium and berkelium. However, the discovery of this new element still needs to be confirmed by another laboratory before it becomes official.



Astatine

Astatine, the rarest naturally occurring element, was discovered in 1940. It is named after the Greek word *astatos*, meaning unstable.



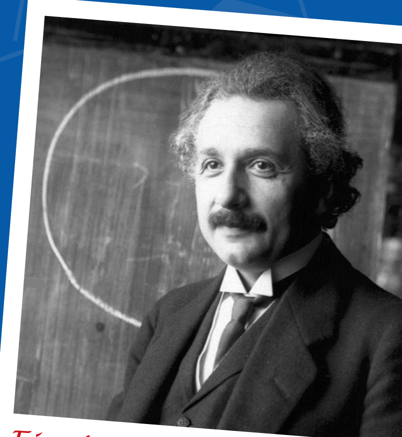
Californium

First produced in the lab in 1950, this radioactive element was named after the state and the University of California where it was discovered.

Yttrium

Discovered in 1828 and named after the Swedish village Ytterby, where the mineral was first found, yttrium is used in LED displays and electrodes.

Wikipedia / Alchemist-hp



Einsteinium

This element, named after Albert Einstein, was discovered in 1952 in the debris of the first hydrogen bomb explosion.

It's Elemental

Actually, Sherlock Holmes said, "Elementary, my dear Watson," but it's close. A collection of 118 existing elements are detailed on the periodic table and range from the most versatile, carbon, to the funny-sounding ytterbium. But what makes each element unique? The answer is actually fairly simple: the number of protons, neutrons and electrons.

Computer chips in many electronics are made from the element silicon, a semiconductor.

Diamond and graphite are both made from the element carbon.

When an element has the same number of protons and electrons but a different number of neutrons, it's called an isotope. Some isotopes are stable and others last only a few nanoseconds.

Elements behave in many different ways. Some have different melting temperatures and some, like hydrogen, helium, nitrogen, oxygen and others, are gases. For instance, to turn helium (He) into a liquid you need to cool it down to -272°C. (The lowest temperature ever recorded on Earth is -89.2°C in Antarctica.) Some elements, like mercury, are liquids at room temperature. Many are solids and some, like molybdenum (Mo), have a melting temperature of 2617°C. By comparison, French fries cook at 400°F, or about 204°C.

The number of electrons and where they are located is important and determines the properties of the elements. Some elements, like copper (Cu), are good conductors, meaning that their properties permit the easy movement of electrons, which creates energy in the form of heat. Others, though, like sulfur (S), are better insulators because their properties prohibit or hinder the movement of electrons so they don't tend to heat up.

Some really neat elements are called semiconductors because sometimes they conduct electrons and other times they don't. One famous semiconductor is silicon (Si), which, depending on what other molecules are around, can sometimes act as an insulator and other times as a conductor.

But perhaps the most versatile of all the elements is carbon (C), which can do all sorts of things like be made into diamonds, the kind of graphite we find in pencils, and even some of the coolest nanoelectronics circuits.

Atom Fun Facts

- The word "atom" comes from the ancient Greek word meaning "undivided." They thought that an atom couldn't be cut into anything smaller, which we now know is not exactly right.
- Atoms are mostly empty space and scientists think that there might be 200 or more subatomic particles. Some of them we already know about—neutrons, electrons, protons, quarks—but others are still waiting to be discovered.
- There are about 2 sextillion (10^{21}) atoms of oxygen in a drop of water.
- There are 92 different elements (atoms) in nature. Scientists have made the rest of them in the laboratory. The first one to be made was technetium, which has an atomic weight of 43.
- A human hair is about 100 nanometers across and that is about 1,000,000 carbon atoms.
- Every year your body replaces about 98% of its atoms.
- The mass of a proton is essentially the same as that of a neutron, but 1,840 times greater than the mass of an electron.
- Hydrogen is the most abundant element in the universe and there are about 10 million known compounds that can be made with carbon.
- There are a total of 15 elements whose atomic symbol is the same as a postal code for a U.S. state: **AL**-aluminum and Alabama, **MN**-manganese and Minnesota, **MO**-molybdenum and Missouri, **IN**-indium and Indiana, **LA**-lanthanum and Louisiana, **ND**-neodymium and North Dakota, **PA**-protactinium and Pennsylvania, **MD**-mendelevium and Maryland, **MT**-meitnerium and Montana, **NE**-neon and Nebraska, **AR**-argon and Arkansas, **CA**-calcium and California, **SC**-scandium and South Carolina, **CO**-cobalt and Colorado, and **GA**-gallium and Georgia.